IM1

MASSACHUSETTS
AGRICULTURAL EXPERIMENT STATION

Bulletin No. 276 June, 1931

Increasing Soil Acidity as a Means of Controlling Black Root-Rot of Tobacco

By William L. Doran

IMPERIAL ... 26 SEPT. 1931 ... INST.

Soils with a pH value of about 5.9 or higher are favorable to the growth of the fungus which causes black root-rot and are therefore unsafe for tobacco. The primary object of the work here described was to study means of lowering the pH value of soil infested with Thielavia basicola, and thereby decreasing the loss caused by black root-rot of tobacco.

MASSACHUSETTS STATE COLLEGE
AMHERST, MASS.

INCREASING SOIL ACIDITY AS A MEANS OF CONTROLLING BLACK ROOT-ROT OF TOBACCO

By William L. Doran, Research Professor of Botany

INTRODUCTION

It has been established by several investigators (5, 24, 13)[1] and it is now well known that a soil made less acid, as by the application of lime, becomes favorable to increased infestation by *Thielavia basicola* (Berk. and Br.) Zopf and to black root-rot of tobacco caused by this fungus. Soils with a pH value of about 5.9 or higher, depending somewhat on soil temperature (14), are therefore unsafe for tobacco, and so they remain until the hydrogen-ion concentration of the soil is sufficiently increased or until the infestation of the soil by the fungus, because of this or some other cause, subsides.

Strains of tobacco resistant to black root-rot may, however, be grown in such soil, and so far as resistant strains, now or later available, are satisfactory to growers and to manufacturers, this is the solution of the problem.

It has sometimes been considered necessary, when such strains were lacking, to use infested soil for some other crop than tobacco until the infestation subsided; but, in the case of a soil otherwise good for tobacco, this is an unsatisfactory solution, for, according to Johnson and Milton (20), it may require as many as ten years for Thielavia to die out in the soil even in the absence of tobacco.

Basic constituents are in the course of years removed from the soil by leaching and in the crops, but the return of an over-limed soil to a sufficiently acid condition to permit good growth of tobacco may be a very slow process, as is illustrated subsequently in the present paper.

The primary object of the work here described was to study means of more quickly lowering the pH value of soil infested with *Thielavia basicola* and thereby decreasing the loss caused by black root-rot of tobacco. It is well known that the pH value of a soil may be lowered by the application of sulfur or acids, and one of the principal objects was to determine to what extent this method is effective and practical in protecting tobacco against black root-rot.

The possibility of using sulfur or an acid for this purpose has already received some attention. In the experiments of Briggs (9), the application of hydrochloric acid to a soil infested with *Thielavia basicola* resulted in a marked reduction in the severity of black root-rot and a small increase in the growth of tobacco. Chapman (12) found that applications of sulfuric acid or sulfur resulted in less black root-rot of tobacco and no interference with growth of the plants. Routt (27) found sulfuric acid beneficial to tobacco (in some cases) when applied to soil infested with Thielavia. According to Anderson and Swanback (7), about 500 pounds of sulfur per acre caused an optimum increase in soil acidity, but they did not record the effect of this treatment on black root-rot or on the yield or quality of tobacco.

[1] Reference is made by number to "Literature Cited," p. 138.

PRELIMINARY EXPERIMENTS

A brief summary of the results of some of these preliminary experiments has already been published (13).

The soil used, except as otherwise indicated, is an ice-deposited stony loam, heavily infested with *Thielavia basicola*. To determine the quantity of each acid necessary to cause the desired lowering of the pH value of the soil, a known number of cubic centimeters of a normal acid was applied in preliminary experiments to each 100 grams of air-dry soil, together with enough water to bring the soil up to 60 per cent of its water-holding capacity. The pH values of the soil were determined at various intervals of time thereafter.[2]

With Sulfuric and Nitric Acids

Sulfuric and nitric acids were about equally effective in increasing the hydrogen-ion concentration of this soil and in reducing the intensity of infection of tobacco by Thielavia; but nitric acid was so toxic to tobacco plants that it was not used in subsequent field experiments.

The growth of tobacco could be correlated with pH value of acidified soil only as each acid was considered separately. For example, an application of nitric acid by which the pH value of the soil was lowered to 5.5 (from 6.0) prevented practically all growth of tobacco, while an application of sulfuric acid by which the pH value of the soil was lowered to 4.6 (from 6.0) permitted good growth of tobacco. The hydrogen-ion concentration of the soil is not the only factor involved, and as Carr and Havercamp (11) have pointed out, the toxicity to plants of an acid applied to soil is possibly attributable to easily soluble salts (as of iron and aluminum) which the acids form in the soil. Be that as it may, it appears that the optimum pH value of soil for the growth of tobacco (and presumably other plants) is not fixed but depends partly on the means by which the soil reaction is adjusted.

With Orthophosphoric Acid

A greater increase in growth of tobacco resulted from the application of orthophosphoric acid than from either sulfuric or nitric acid; although orthophosphoric acid had much less effect in lowering the pH value of the soil than either of the others, and did not at all reduce the intensity of infection by Thielavia. Whenever orthophosphoric acid was applied to soil infested with this fungus, black root-rot was severe or rather more severe, although the pH value of the soil was thus lowered as much as to 5.0; but when orthophosphoric acid was applied to soil not limed and not heavily infested with Thielavia, no increase in black root-rot resulted.

In one series of pot experiments, orthophosphoric acid, in the amounts named in Table 1, was applied to limed soil infested with Thielavia, and tobacco plants were grown in soil so treated. The initial pH value of this soil was 5.9. The application of orthophosphoric acid lowered the pH value of

[2] In the preliminary experiments and in the field experiments in 1926 and 1927, the pH values of the soil were determined colorimetrically by a method previously described (3). The soil pH values in the field in 1928, 1929, and 1930 were determined electrometrically.

TABLE 1.—EFFECTS OF ORTHOPHOSPHORIC ACID ON pH VALUES OF SOIL AND ON GROWTH AND BLACK ROOT-ROT OF TOBACCO IN LIMED SOIL.

Orthophosphoric acid per 100 grams dry soil c.c. of N/1 acid	pH values of soil	Black root-rot	Dry weights of plants Grams
None	5.9	Moderate to severe	8.54
15	5.0	Severe	12.40
20	5.0	Severe	22.04
25	5.0	Severe	17.54

the soil from 5.9 to 5.0, but black root-rot of tobacco was nevertheless severe—rather more severe at pH 5.0 with orthophosphoric acid than at pH 5.9 without this acid. The degrees of infection may be seen by reference to Figure 1. Plants were larger, however, with orthophosphoric acid than without it.

It is evident from this that other factors than or in addition to the hydrogen-ion concentration of the soil are involved. This soil with its pH value lowered by orthophosphoric acid far below the usually accepted danger point for black root-rot was no less, in fact it was little more favorable to infection of tobacco by Thielavia than the same soil with the initial pH value of 5.9 but without treatment with orthophosphoric acid.

Some phosphorus is of course necessary for the growth of tobacco, although according to Anderson and his co-workers (4) tobacco on old tobacco land in Connecticut may be grown without any carrier of phosphorus in the fertilizer mixture, since large quantities have accumulated in such soils.

The work here described was confined to pot experiments, but so far as these results are indicative, they suggest applying no more phosphorus than is necessary for the best growth of tobacco when one object is to hasten the dying-out of Thielavia in over-limed and infested soil.

As described in a later part of this paper, however, there was no increase in black root-rot when sulfuric acid and orthophosphoric acid were used together in the field.

With Aluminum Sulfate and Sulfur

It is possible that certain soluble toxic substances, for instance salts of aluminum, in addition to (or instead of) hydrogen-ion concentration, inhibit the growth of *Thielavia basicola* in acid soil, and that orthophosphoric acid as well as lime inactivates these toxic substances with consequent benefit to the fungus. This is in line with the explanation by Carr and Havercamp (*loc. cit.*) of the beneficial effect of phosphoric acid on growth of plants, i. e., phosphoric acid forms less available and less toxic compounds with iron and aluminum in the soil.

Sulfur, sulfuric acid, and aluminum sulfate ($Al_2 (SO_4)_3 .18H_2O$), separately or together, were added to soil infested with *Thielavia basicola*, and tobacco plants were grown in this soil (in 2-gallon crocks). The effects of each treatment on soil pH value, dry weight of plants, and black root-rot are recorded in Table 2.

The pH value of the soil was lowered by all treatments, but more by aluminum sulfate with sulfuric acid or sulfur than by either of these chemicals alone. All of the acidification treatments reduced the severity of black root-rot, although none of them eliminated it.

TABLE 2.—EFFECTS OF ALUMINUM SULFATE ALONE AND WITH SULFURIC ACID OR SULFUR ON pH VALUES OF SOIL AND ON GROWTH AND BLACK ROOT-ROT OF TOBACCO IN LIMED SOIL.

Soil treatment (Grams per pot)	pH values of soil After 2 weeks	After 11 weeks	After 18 weeks	Dry weights per plant* Grams	Relative numbers	Black root-rot
Check	6.2	6.0	5.9	25.41	100	Severe
Sulfuric acid 5.9	5.2	5.1	5.2	32.63	128	Mild to moderate
Sulfur 1.9	5.5	5.3	5.3	31.43	124	Mild to moderate
Aluminum sulfate 4.4 } Sulfuric acid 5.9 }	5.0	5.0	5.1	22.89	90	Mild to moderate
Aluminum sulfate 4.4 } Sulfur 1.9 }	5.3	5.1	5.2	36.24	142	Mild to moderate
Aluminum sulfate 6.5 } Sulfuric acid 5.9 }	4.9	4.9	5.3	26.41	104	Mild to moderate
Aluminum sulfate 6.5 } Sulfur 1.9 }	5.2	4.8	4.8	27.02	106	Mild to moderate
Aluminum sulfate 4.4	5.5	5.5	5.7	26.39	104	Mild to moderate
Aluminum sulfate 6.5	5.7	5.2	5.2	20.91	82	Mild to moderate

* Means for duplicate treatments.

Aluminum sulfate used alone resulted in no significant increase in dry weight of plants; in fact, the heavier application interfered with growth. Dry weights of plants were increased 28 per cent by sulfuric acid and 24 per cent by sulfur; but this same application of sulfur when used with aluminum sulfate resulted in an increase in dry weights of plants of 42 per cent.

It appears from this that aluminum sulfate added to the soil had an unfavorable effect on *Thielavia basicola,* and that the effect on the disease which this fungus causes was greater when the soil acidity was further increased as by the use of sulfur.

With Sulfuric and Orthophosphoric Acids Used Together

The pH value of soil was lowered as much by sulfuric or nitric acid alone as by the use of either of them with orthophosphoric acid; but tobacco grew better when orthophosphoric acid was used with sulfuric or nitric acids than when either of the last two named acids was used alone. In the preliminary experiments there was rather less black root-rot when sulfuric or nitric acid was used alone than when either of them was used with orthophosphoric acid, but this effect of the latter was more than offset by the improved growth of the plants.

On the basis of these experiments it was decided to use (together) sulfuric acid, 1800 pounds per acre, and orthophosphoric acid (80 per cent), 440 pounds per acre, in the field experiments subsequently described. The quantity of acidifying chemical necessary to apply to a soil in the field to cause a

desired lowering of pH value of the soil and the quantity which may be applied with safety to plants, may vary with the soil and cannot be predicted with any degree of exactness except by preliminary experiments with the particular soil.

In one series of these preliminary experiments, the same acid treatments were applied to two soils. One of these, a water-deposited fine silt loam high in organic matter, was well buffered and resisted change in its pH value. The other soil, an ice-deposited stony loam, was not as well buffered and its pH value was consequently more readily lowered by the same application of an acid. As has been pointed out by others (28, 21) the effect of an application of acid on the pH value of soil and on plants and fungi in that soil depends on the type of soil. Acids in the the same quantities were somewhat more toxic to plants in the well-buffered soil.

FIELD EXPERIMENTS

Methods and Plan of Work

These experiments (except as otherwise indicated) were carried on in a field the history and plot treatments of which up to 1925 have already been described (5). Certain plots had received applications of lime to a total of 5 tons per acre, the last of which was applied in 1923. In these limed plots pH values were high enough to favor *Thielavia basicola*, black root-rot was severe, and yields of tobacco were consequently low. Tobacco was grown on all plots from 1922 to 1925 inclusive. Soil treatments and crops of each plot from 1926 to 1929 inclusive were as recorded in Table 9.

The fertilizers used each year and the amounts of each material are shown in Table 10. These were applied immediately before tobacco plants were set.

In 1926 sulfur (inoculated), 200 or 400 pounds per acre, or sulfuric acid, 1800 pounds, together with orthophosphoric acid (80 per cent), 440 pounds per acre, were applied to the plots so indicated in Table 9. This was done one month before plants were set. The acids and the sulfur were harrowed into the soil immediately after their application. In 1927 sulfur and the acids were applied again and in the same amounts to the plots named in Table 9, two months before the tobacco plants were set. Some plots received these treatments, therefore, in one year only, and others received them in two successive years. No acidifying chemicals were applied after 1927.

In order to determine how tobacco compared with some other crops in removing lime from the soil and in lowering the pH value of soil, timothy was planted in the fall of 1925 and alfalfa and alsike clover in the spring of 1926 on the plots indicated in Table 9. The hay crops were grown on these plots in 1926 and 1927. In 1928 half of each hay plot was again set with tobacco, and in 1929 and 1930 the other half of each hay plot was again used for tobacco. There were thus available for comparison plots on which tobacco was grown every year and plots on which tobacco was grown following two or three years of each of these other crops—alfalfa, alsike clover, or timothy.

Each year the tobacco from each of the several plots was cut, cured, stripped, and sorted separately. The fire-holding capacity or duration of burn of samples of leaf from each plot was determined in strip tests.[3] The quantities of calcium and magnesium oxides removed in each crop (including stalks

[3] The burn of the leaves was initiated by means of an electrical resistance coil. Five leaves from each grade were used and four tests were made on each leaf.

of tobacco) from each plot were determined.[4] Roots of tobacco plants were examined for black root-rot and brown root-rot at the time the tobacco was cut.

The pH value of the soil, the yields per acre of cured leaf, the results of the sorting, burn tests, and root examinations are recorded for each plot and each year so far as they are available, in Tables 11-15 in the appendix.

Effects of Lime

On pH values of Soil and on Yields of Tobacco.

The pH values of the soil in limed plots 12 and 24 may be compared with the pH values of soil in unlimed plots 5, 17, 6, and 18 by reference to Tables 11-15, for the years 1926, 1927, 1928, 1929, and 1930. None of these plots received sulfur or acids.

The pH value of limed soil did not change more than 0.2 from 1926 to 1930 inclusive, and that change was from about 5.9 to 6.1, or not in the direction of increased acidity. Soil pH values in limed plots were still favorable to *Thielavia basicola* in 1930, seven years after the application of lime. The soil in plots not limed had meanwhile become increasingly acid, the pH values changing from about 5.4 in 1926 to about 5.0 in 1930.

In Table 3 the yields of tobacco on plots not limed are compared with the yields on the limed plots, and the losses in yield on limed plots, expressed as percentages of yields on plots not limed, are recorded. Tobacco was grown every year on all of these plots and to none of them were acidifying chemicals applied.

TABLE 3.—EFFECTS OF LIME (APPLIED LAST IN 1923) ON YIELDS OF TOBACCO FROM 1925 TO 1930, INCLUSIVE.

Year	Yields per acre*		Loss in yield on limed plots
	Unlimed plots	Limed plots	
	Pounds	*Pounds*	*Per cent*
1924	1548	1395	10
1925	1230	673	45
1926	1648	935	43
1927	1536	987	35
1928	789	920	None
1929	1519	1170	23
1930	1924	1438	25

* Means for duplicate plots.

The loss caused directly by black root-rot (as evidenced by root examinations) on plots last limed in 1923, reached its maximum (45 or 43 per cent) in 1925 and 1926, and was considerably less in 1927.

In 1928 the total precipitation in June, July, and August was 74 per cent more than the normal for this period. As Chapman (12) has pointed out, excessive summer rainfall in Massachusetts is always followed by a reduction in the yield of tobacco. Furthermore, the soil in this field is not very well

[4] By Philip H. Smith and Henri D. Haskins of Massachusetts Agricultural Experiment Station.

drained, and under these conditions of excessive rainfall tobacco grew so poorly on all plots that the effects of the several soil treatments on growth were largely obscured. Yields on all plots, limed or not limed, were the lowest they had ever been, and topography of the field had for the first and only time some effect on the growth of tobacco; in thirteen out of seventeen pairs of duplicate plot treatments, the plots in the lower half of the field yielded less than the plots in the higher half of the field.

Limed plots yielded 23 per cent less in 1929 and 25 per cent less in 1930 than did plots not limed. Thus, seven years after liming, the soil was still sufficiently favorable to *Thielavia basicola,* as evidenced by yields (and infection of roots), to prevent the profitable growing of tobacco on limed plots. But the loss caused by lime, applied in 1923, decreased from 45 per cent in 1925 to 23 per cent in 1929.

On Quality and Burn of Tobacco

The index of quality used for purposes of comparison is the percentage of leaf of the grades lights, mediums, and seconds in the tobacco from each plot.

In general, lower yields on limed plots were associated with poorer quality. In 1926 (Table 11) 48 per cent (mean for duplicate plots 5 and 17) of the tobacco from plots without lime was mediums and seconds, and only 26 per cent (mean for duplicate plots 12 and 24) of the tobacco from limed plots was so classed. Again in 1927 (Table 12), there was a higher percentage of mediums and seconds from plots not limed than from limed plots. But in 1928, 1929, and 1930 (Tables 13-15), with smaller differences in yield between limed and unlimed plots than in earlier years, the quality of tobacco on limed plots was not definitely inferior to the quality of tobacco on plots not limed.

In addition to the crops of the years discussed in this paper, the burn of the tobacco of the crops of 1924 and 1925 (described in an earlier report (5) from plots with and without lime was tested.[5]

In 1924, the first year after the last application of lime, the fire-holding capacity of both darks and seconds from limed plots was considerably better than that of corresponding leaves from plots not limed, as may be seen by reference to Table 4.

TABLE 4.—FIRE-HOLDING CAPACITY OF TOBACCO, CROP OF 1924.

Grade of leaf	Soil treatment	Percentage of tests in which the burn was: Good *Per cent*	Fair *Per cent*	Poor *Per cent*
Seconds	Limed plots	56	37	7
	Plots not limed	25	42	33
Darks	Limed plots	30	50	20
	Plots not limed	0	54	46

In five out of six comparisons made in the crop of 1925, the fire-holding capacity of the seconds was better without lime than with it. In six out of nine comparisons of the darks in this crop, the fire-holding capacity was as

[5] The burn of the crop of 1924 was tested by Walter Edwards and that of 1925 was tested by J. P. Jones, formerly Research Professor of Agronomy in Massachusetts Agricultural Experiment Station.

good without lime as with lime; but in the other three comparisons, burn was of longer duration with lime than without it. The differences were not great, and the only conclusion is that the burn of the tobacco of 1925 was not consistently better or worse in limed plots than in plots not limed.

From Table 11 it is seen that the burn of the crop of 1926 was somewhat better with lime (Plots 12 and 24) than without it (Plots 5 and 17). The increases in fire-holding capacity on limed plots were 45 per cent in the mediums, 24 per cent in the seconds, and 61 per cent in the darks.

In 1927, however, liming did not consistently improve the burn. Lime was associated with a better burn of the seconds on one plot (Plot 24) but not on its duplicate (Plot 12), and in three out of four possible comparisons lime did not improve the burn of the darks. (Table 12.)

The fire-holding capacity of the crop of 1928, the year of the rainiest growing season, was very good on the whole, and the burn of both darks and seconds from plots not limed was as good as or better than the burn of the corresponding leaves from limed plots. (Table 13.)

In 1929 seconds from limed plots 12 and 24 held fire slightly longer (mean of 29 seconds) than did leaves of this grade from plots 5, 6, 17, and 18, not limed, (mean of 26 seconds); but darks from the limed plots did not hold fire quite as long (mean of 16 seconds) as did darks from the unlimed plots (mean of 18 seconds). The differences are small and inconsistent and show only that liming was without significant effect on burn in 1929. (Table 14.)

In four out of these six years lime in the amounts applied to this soil did not improve burn of the leaf; that is, it did not increase the fire-holding capacity as determined by strip tests. In only two years, 1924 and 1926, did lime improve burn.

These results are in general agreement with those presented in the literature on this subject. In the experiments of Ames and Boltz (1), the application of lime to the soil shortened the time of burning of tobacco. According to Haley (18), lime does not improve the combustion of cigar leaf to any extent and if applied in large quantities it may injure burn. Garner (16) has reported that lime does not much affect the fire-holding capacity of tobacco. Lime reduced the fire-holding capacity of tobacco in strip tests, but not in cigar tests, in Connecticut (6).

Considering only unlimed plots 5 and 17, the best burn of these four years was in the rainiest season and the poorest burn was in the dryest season. The differences were greater than those associated with lime or no-lime treatments of the soil.

Year	Rainfall (June, July, Aug.)	Length of burn in seconds (Unlimed Plots 5 and 17)	
		Darks	Seconds
1926	9.25	6	9
1927	11.78	13	13
1928	21.60	41	25
1929	12.11	13	20

Effects of Tobacco, Alfalfa, Timothy, and Alsike Clover

On Soil Reaction and Removal of Lime in the Crops

The number of pounds of calcium and magnesium oxides removed in each of these crops from each plot in 1926, 1927, and 1928 is recorded in Table 5.

TABLE 5.—CALCIUM AND MAGNESIUM OXIDES REMOVED FROM SOIL IN CROPS, 1926, 1927, AND 1928.

Plot No.	Crop	CaO and MgO Pounds per acre	Plot No.	Crop	CaO and MgO Pounds per acre
1b	Alsike clover	113.45	13b	Alsike clover	127.75
2a	Timothy	78.34	14a	Timothy	81.03
3a	Tobacco	339.05	15a	Tobacco	334.58
3b	Tobacco	312.09	15b	Tobacco	336.08
4a	Tobacco	277.56	16a	Tobacco	324.87
4b	Tobacco	324.17	16b	Tobacco	322.94
5	Tobacco	306.49	17	Tobacco	333.78
6	Tobacco	277.71	18	Tobacco	297.20
7b	Alfalfa	189.73	19b	Alfalfa	209.63
8a	Timothy	82.91	20a	Timothy	101.69
9a	Tobacco	214.18	21a	Tobacco	267.87
9b	Tobacco	201.91	21b	Tobacco	264.07
10a	Tobacco	261.43	22a	Tobacco	293.78
10b	Tobacco	255.97	22b	Tobacco	303.61
11a	Tobacco	312.28	23a	Tobacco	357.88
11b	Tobacco	292.77	23b	Tobacco	310.10
12	Tobacco	182.53	24	Tobacco	209.89

From limed plots, in the absence of acidifying treatments, alfalfa removed as much calcium and magnesium oxides as did tobacco (but no more), and timothy did not remove half as much as did tobacco. Tobacco was similarly more effective than alsike clover on plots not limed.

Much more of the calcium and magnesium oxides was removed by tobacco on limed plots acidified with sulfur or with sulfuric and orthophosphoric acids than by tobacco, alfalfa, or timothy on limed plots not acidified.

The effects of tobacco, alfalfa, and timothy on the pH values of soil in limed plots in the years 1926 to 1930, inclusive, may be compared by reference to Tables 11-15. The pH values of the soil in all of these limed plots were about 6.0 or 6.1 in 1930, and in no case were they lower in 1929 and 1930 than in 1926; in fact, they were all somewhat higher in the last two years.

The substitution of alfalfa or timothy for tobacco for two or three years did not result in soil reactions any less favorable to *Thielavia basicola*. If, or when, these crops have any effect on black root-rot of tobacco which may follow them in a rotation system, this effect is apparently exerted through some other factor than soil reaction.

Alfalfa and Black Root-Rot

Black root-rot caused by *Thielavia basicola* has been reported (2, 19) as occurring on several species of legumes, including alfalfa. There is an opinion (12, 17), therefore, that legumes should not be grown preceding tobacco in a cropping system. According to Major (22) and Burkholder (10), alfalfa is susceptible to infection by *Thielavia basicola;* but in experiments by Johnson (19) the susceptibility of alfalfa to this fungus was classed as low (compared with that of other hosts). Thielavia has been reported (2) as occurring on alfalfa in only three states, although the roots of alfalfa have presumably been examined by plant pathologists in many more.

The results of the observations now to be described indicate that alfalfa is not sufficiently susceptible to black root-rot caused by Thielavia to preclude, for that reason, the growth of alfalfa in rotation with or preceding tobacco.

The soil of the limed plots on which alfalfa was grown following four years of tobacco was very completely infested with Thielavia, as evidenced by the severe infection of tobacco in the preceding and the succeeding years. The relative susceptibility or resistance of alfalfa to infection by this fungus was, therefore, put to a real test.

Roots of alfalfa were examined each year. The roots showed a kind of pitting very similar in appearance to an injury of undertermined cause which has been described by other investigators (31, 29); but no infection by *Thielavia basicola* was found, although soil conditions and the abundant presence of the fungus were most favorable to it.

As far as black root-rot is concerned, therefore, there seems to be no reason why alfalfa cannot be grown in a rotation preceding tobacco.

On Black Root-Rot, Brown Root-Rot, and Yields of Tobacco

In 1928, 1929, and 1930, the first, second, and third years of tobacco after the hay crops, black root-rot of tobacco on limed plots was slightly less severe (a little less conspicuous in its effects on the roots) than on plots on which tobacco had been grown every year. This effect was too small, however, to offset the brown root-rot effect of the hay crops on the tobacco which followed them, at least in the first year or two.

Brown root-rot of tobacco following timothy was equally severe on plots with and without lime in 1928, the first year of tobacco. It was much less severe in 1929, the second year after the hay crops. In 1930, the second or third year of tobacco following the hay crops, there was little and in most cases no brown root-rot; that is, the brown root-rot effect of these predisposing crops on the tobacco which followed them disappeared after the first one or two years of tobacco.

In the very rainy season of 1928, lowered yields and poor quality of tobacco were associated with a preceding alfalfa crop only in the lowest part of the field, where all tobacco grew poorly. Tobacco yielded as well after alfalfa as after tobacco in the highest part of the field, and here the tobacco was of as good quality following alfalfa as on plots where only tobacco had been grown. In 1929 limed plots on which alfalfa was grown in 1927 and 1928 yielded 4 to 17 per cent less tobacco than did plots in continuous tobacco; but limed plots on which tobacco was grown no later than 1927 yielded 15 to 30 per cent more tobacco than did limed plots on which tobacco was grown every year. In 1930 the yield of tobacco following alfalfa, grown in 1926 and 1927 or in 1926, 1927, and 1928, was practically the same but no more than the yield on plots in continuous tobacco. The bad effect of brown root-rot on yields of tobacco following alfalfa was, therefore, confined to the first year of tobacco. In the second year of tobacco after alfalfa there was some increase in yield as compared with yield of plots cropped continuously with tobacco; and in the third year, yields were about the same following alfalfa as on plots on which tobacco was grown every year.

With brown root-rot severe, the bad effects of timothy on the yield of tobacco which followed it in 1928 were essentially the same on plots not limed (on which the depressions in yield were 16 to 27 per cent) as on plots limed (on which the depressions in yield were 17 to 33 per cent). In 1929 yields

of tobacco on limed plots on which timothy was grown in 1927 and 1928 were 17 and 37 per cent less than yields on plots cropped continuously with tobacco. Two years of timothy were, therefore, much more injurious than were two years of alfalfa. However, the yield of tobacco the second year after timothy, last grown in 1927, was as good as on plots where tobacco followed tobacco. There was, however, no really increased yield of tobacco on limed plots resulting from the substitution of timothy for tobacco in previous years. In 1930 tobacco on limed plots following timothy yielded as well as (in fact a little better than) tobacco on plots on which only tobacco was grown in earlier years.

Alsike clover was confined to plots not limed, and its effect on the tobacco which followed it may, therefore, be compared only with that of timothy. It was much less injurious than was timothy. Timothy was associated with a loss in yield of tobacco of 81 or 69 per cent in 1928, while the loss in yield of tobacco following alsike clover was 45 or 49 per cent (in duplicate plots).

The substitution of these hay crops for tobacco on limed and Thielavia-infested soils is not to be recommended as a means of increasing soil acidity or overcoming black root-rot in later crops of tobacco.

Effects of Sulfur and of Acids in the Field

On pH Values of Soil

The effects of the several acidification treatments on pH values of soil in limed plots from 1926 to 1930, inclusive, are recorded in Tables 11 to 15. The actual pH values which resulted from each of the several treatments are significant only in connection with this one soil; for as indicated by results in another field described below, and as pointed out by other investigators (23, 21), sulfur (or sulfuric acid) may not give the same results in soils of different types. However, the relatively small changes in pH value of soil which resulted from the application of sulfur or the acids to limed plots were accompanied by materially increased yields of tobacco and less black root-rot.

The pH values of the soil in limed plots to which the acidifying chemicals were applied only in 1926, one month before tobacco plants were set, were as low in that year (pH 5.6 to 5.8) as in the following years; that is, these treatments did not lower the pH value of the soil increasingly after the first year. This is as would be expected, for in experiments by other investigators (26, 15, 30), 80 per cent or more of the sulfur applied to soil was oxidized within a month or during the growing season; and McKibben (23) observed that the acid effect of sulfur applied to soil reached its maximum within two or three months.

The applicaton of sulfuric and orthophosphoric acids in 1926 resulted in sufficiently lowered pH values of the soil (to about 5.7) in 1926 and 1927 but not in 1928 or 1929. The application of these acids in two successive years, 1926 and 1927, resulted in lowered pH values (to 5.6 or 5.7) in every year through 1930. Nine weeks after this treatment was applied in 1927, the pH value of the soil was lowered 0.2 or 0.3 by it.

Sulfur, 400 pounds per acre, applied in 1926 lowered the soil pH values to 5.7 from 5.9 in 1926 and 1927, and it had less but some effect in 1928, 1929 and 1930. The application of 400 pounds of sulfur in 1926 and again in 1927 resulted in lowering the pH values of the soil in 1927, 1928, 1929, and 1930.

Sulfur, 200 pounds per acre, applied in 1926 or in 1926 and 1927 was less

effective than the heavier application; pH values were lowered by it in 1926 and 1927 but not in the following years.

On this heavily limed soil, 400 pounds of sulfur rather than 200 pounds per acre were needed to lower the pH value of the soil effectively. Sulfur, 400 pounds, applied once was effective for two years. Sulfur, 400 pounds, applied in two successive years, 1926 and 1927, remained effective through 1930. In 1930 limed soil not acidified had a pH value of 6.0, and limed soil to which 400 pounds of sulfur had been applied in both 1926 and 1927 had a pH value of 5.7 or a little below the usually accepted danger point for black root-rot.

On Black Root-rot

The severity of black root-rot on limed plots in 1926 was reduced by all acidification treatments but by none of them was it eliminated. The disease was present as a trace on plots not limed, severe on plots limed and not acidified, and moderate or mild to moderate on limed plots acidified, without very pronounced differences between the several acidification treatments.

In 1927 the degree of infection of tobacco by *Thielavia basicola* was greatly reduced by sulfuric and orthophosphoric acids applied in 1926 and 1927. On one of the limed plots so treated, there was no black root-rot and on the other there was only a trace. Black root-rot on the check plots, limed and not acidified, was less severe than the year before, but it was at least moderate in intensity. Infection of tobacco on limed plots was reduced more in 1927 by the application of sulfur in the two successive years than by its application in 1926 only.

In 1928 black root-rot of tobacco was again severe on limed plots and absent, as in every year, from plots not limed. Its severity on limed plots was reduced most this year on those plots to which the acids or sulfur, 400 pounds per acre, was applied in 1926 and 1927; but sulfuric and orthophosphoric acids permitted more infection by Thielavia in 1928 than in 1927, the last year they were applied.

There was black root-rot in 1929 on all tobacco plants on limed plots not acidified, but the infection was no more than moderate. On limed plots, there was least black root-rot on those to which sulfuric and orthophosphoric acids were applied in 1926 and 1927. On these plots there was only a trace of the disease on many of the plants and some of the plants were entirely free from it. The next most nearly disease-free of the limed plots were those to which these acids were applied in 1926. The applications of sulfur, 200 or 400 pounds per acre, in 1926 and 1927 resulted in less black root-rot in 1929 than did the application of these amounts of sulfur in one year (1926) only.

In 1930 black root-rot was no worse than moderate, even on limed plots not acidified. The acidification treatment of limed plots which resulted in least black root-rot this year was the application of 400 pounds of sulfur per acre in 1926 and 1927 or in 1926 only.

On Yields

The percentage increases in yields of limed and acidified plots, for example plots 9a and 21a (duplicates), over yield of check plots 12 and 24, limed but not acidified, may be seen by reference to Table 6. In each case the yield of a limed plot acidified was compared with the yield of the most nearly adjacent limed plot not acidified.

TABLE 6.—INCREASE IN YIELD OF TOBACCO ON LIMED PLOTS RESULTING FROM ACIDIFICATION TREATMENTS OF SOIL.

Plot No.	Acidification treatment (Pounds per acre)	Increase in yield*—per cent				
		1926	1927	1928	1929	1930
9a, 21a	Sulfur 200, in 1926 and 1927		49.0	None	20.5	11.0
9b, 21b	Sulfur 200, in 1926 only	27.5	34.0	None	14.0	8.0
10a, 22a	Sulfur 400, in 1926 and 1927		43.5	None	14.0	17.0
10b, 22b	Sulfur 400, in 1926 only	34.5	50.5	None	12.5	16.0
11a, 23a	Sulfuric acid 1800 + orthophosphoric acid 440, in 1926 and 1927		87.0	4.5	19.5	18.0
11b, 23b	Sulfuric acid 1800 + orthophosphoric acid 440, in 1926 only	58.5	33.5	20.0	10.5	2.0

* Means for percentage increase in yields of duplicate limed plots acidified, over their most nearly adjacent check plots (limed but not acidified).

Beginning in 1926, the tobacco on limed plots grew much better on those plots which had received applications of sulfur or of sulfuric and orthophosphoric acids than on plots not acidified. The beneficial effect of the acids in 1926 on the growth of plants on limed plots, as compared with growth on limed plots not acidified, is shown in Figure 2. Yields of tobacco on limed plots were increased by all treatments as compared with yields on limed plots not acidified.

The application of sulfur to plots not limed, and therefore without black root-rot as a factor, did not significantly affect yields that year. (In another field with a less well-buffered soil, its pH value two months after the treatments was lowered as follows from an initial pH value of 6.2: by sulfuric acid, 2000 pounds per acre, 0.6; by sulfuric acid, 2000 pounds, and orthophosphoric acid, 500 pounds per acre, 0.6; by orthophosphoric acid, 1000 pounds per acre, 0.3; and by sulfur (inoculated), 400 pounds per acre, 0.4 In the practical absence of *Thielavia basicola* from the soil of this field, none of these treatments affected the yields of tobacco).

In 1927 limed plots to which sulfuric and orthophosphoric acids had been applied for two years (1926 and 1927) yielded as much as plots without lime (and of course without black root-rot). The application of these acids to limed plots for one year only increased yields in 1927 much less than in 1926, the year of application.

Sulfur, 200 or 400 pounds per acre, applied in 1926 increased yields on limed plots more in 1927 than in 1926, the year of its application. Sulfur, 400 pounds per acre, was more effective in increasing yields in both years than was sulfur, 200 pounds per acre.

Sulfur applied to plots not limed, and with black root-rot not a factor, resulted in 1927 either in no effect on yields or in increased yields, as compared with yields of plots not limed and not acidified. Even on unlimed plots 4a and 16a (with soil pH value 5.5) to which sulfur to a total of 800 pounds per acre was applied in 1926 and 1927, yields in 1927 were 6 or 17 per cent larger than the yields of the nearest plots, 6 and 18 respectively, without lime and without acidification. Similarly, on unlimed plots 4b and 16b, to which sulfur, 400 pounds per acre, was applied in 1926, yields were increased in 1927 by 34 and 16 per cent respectively, as compared with yields of nearest plots not limed and with no sulfur. Even these relatively heavy applications

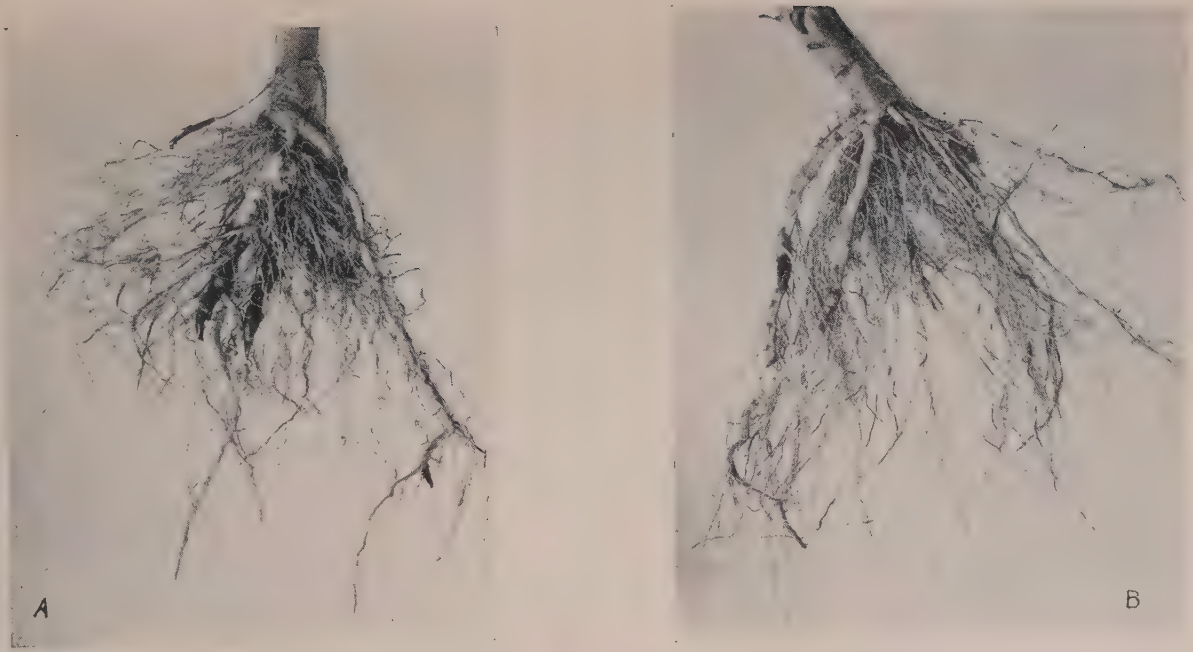

Fig. 1.– Effect of Orthophosphoric Acid on Infection of Tobacco by Thielavia basicola.
A. Typical infection in soil with pH value 5.9 without acid.
B. Typical infection in this soil when its pH value had been lowered to 5.0 by orthophosphoric acid.

Plot 11 is a limed plot to which sulfuric and orthophosphoric acids were applied in 1926.

Plot 12 is a limed plot without acidification.

Fig. 2.—Growth of Tobacco in 1926 on Limed Plots with and without Soil Acidification. (Photographed August 1.)

of sulfur to a relatively acid soil did not interfere with the growth of tobacco. Sulfur did, however, increase yields more on limed plots with black root-rot consequently a factor than on plots not limed.

On the basis of yields in 1927, the optimum rate of application of sulfur for this soil was nearer 400 than 800 pounds per acre. Yields of tobacco on limed plots were increased more in 1927 by sulfur, 400 pounds per acre, applied in 1926 than by sulfur, 400 pounds per acre, applied in 1926 and again in 1927, or a total of 800 pounds.

In 1928, for the first and only time, yields were larger on limed plots than on plots not limed. (Table 13.) In this abnormally rainy season, the effects of sulfur on yields of plots not limed were inconsistent; there were increased yields on some of the plots, following some of the treatments, but on duplicate plots yields were lower than on the check plot without sulfur. Yields on limed plots in 1928 were not consistently increased by sulfur. On the lower part of the field growth was very poor regardless of all factors except too much water in the soil. The yields in 1928 on limed plots to which sulfuric and orthophosphoric acids were applied in 1926 were 21 and 19 per cent greater than those of their checks, plots 12 and 24 respectively, limed but not acidified.

Yields of tobacco in 1929 (Table 14) on limed plots acidified were greater, as in earlier years, than were yields of tobacco on limed plots not acidified. The acidification treatments of limed plots which were most effective in increasing yields were sulfur, 200 pounds per acre applied in 1926 and 1927, and sulfuric and orthophosphoric acids applied two years. The other acidification treatments resulted in increases of from 8 to 14 per cent on limed plots. Acidification treatments of limed plots did not increase yields as much in 1929 as they did in 1926 and 1927. The application of sulfur to plots not limed, and with black root-rot consequently not a factor, did not significantly or consistently affect yields in 1929.

In 1930 the yields of tobacco on limed plots were increased 16, 17, or 18 per cent by sulfur, 400 pounds per acre applied in 1926, the same applied in 1926 and 1927, or the acids applied in 1926 and 1927. (Table 15.) These increases were about the same as those resulting in 1929 from the same treatments; but as in 1929, the increases were much less than in 1926 and 1927, the years of or immediately following the application of the acidifying treatments. In 1930, as in most cases in the earlier years, yields of tobacco on plots not limed were not materially affected by sulfur.

Sulfur (not inoculated) was applied in 1930 to the soil of another field here designated as Field Y, at the rate of 600 pounds per acre. The application was made in April, at which time the pH value of this soil was 7.0. The effects of this application on the pH value of the soil are shown in Table 7.

The pH values of the soil in the plots which received sulfur were lower than those of their checks by 0.2 to 0.6 on July 16. The pH value of this soil was so high in the beginning, however, that although the pH value was lowered as much as to 6.1, it was not enough to prevent black root-rot, and yields of tobacco were unaffected.

In these experiments, then, the application of sulfur to soil increased yields of tobacco markedly and consistently when the soil was infested with Thielavia and when the pH value of the soil was lowered by the sulfur to below 5.9, but not under other conditions.

TABLE 7.—EFFECT OF SULFUR ON pH VALUES OF SOIL IN FIELD Y.

Plot No.	Treatment	pH values of soil		
		June 11	July 16	August 27
1	Check	7.0	7.0	7.0
1a	Sulfur	6.1	6.3	6.4
2	Check	7.2	7.0	7.2
2a	Sulfur	6.9	6.8	6.5
3	Check	7.0	7.0	.....
3a	Sulfur	6.9	6.8	.....
4	Check	6.7	6.8	.....
4a	Sulfur	6.3	6.2	.....

On Grades of Leaf

These comparisons are based on the percentages of tobacco from each plot which were sorted into lights, mediums, and seconds, as contrasted with darks and fillers. (See Tables 11-14, for the years 1926, 1927, 1928, and 1929.)

On this basis, the grades as well as the yield of tobacco on limed plots were improved in 1926 and 1927 by the use of sulfur or the acids, sulfuric and orthophosphoric. In 1927, the grades of the tobacco on plots not limed were either improved or unaffected by the applications of sulfur in 1926 and 1927.

Quality was poor on most of the plots in the very rainy summer of 1928 in which the acidification treatments were ineffective in increasing yields. The only treatment which resulted in improved grades of tobacco on limed plots in the lower part of the field that year was the application of sulfuric and orthophosphoric acids in 1926. This treatment as well as sulfur, 200 pounds per acre applied in 1926 or in 1926 and 1927, improved the quality of tobacco on limed plots in the higher part of the field.

In 1929, with larger yields and better quality of tobacco on limed plots than in earlier years, the quality of tobacco was not affected by the acidification treatments either on plots limed or on plots not limed.

In 1930, with black root-rot less severe than in earlier years, the percentage of leaves of the grades lights, mediums, and seconds on limed plots acidified (except by sulfur, 200 pounds per acre applied in 1926) were a little less than the percentages of leaves of these grades on limed plots not acidified.

In 1926, 1927, and 1929, however, the quality of the tobacco was not injured by the sulfur or the acids used on this soil. Similarly, in the experiments of McKibben (23) the quality of tobacco was not affected by sulfur applied to the soil.

On Burn

In experiments of Murwin (25), sulfates (of sodium or magnesium) did not injure the burn of tobacco; but on the basis of other work in Connecticut (8), it was concluded that sulfates in the leaf are injurious to burn, and that the application of sulfates (sulfate of potash) to the soil increases the percentage of sulfates in the leaf. It has been found (8), however, that the ability of the tobacco plant to absorb increased quantities of sulfur is very

limited, which is probably fortunate if sulfur is to be of use in the protection of tobacco against black root-rot.

The effect on burn of tobacco of applications of sulfur to soil limed and not limed may be seen by reference to Table 8.

The fire-holding capacity of the tobacco on limed plots was reduced by the acidification treatments in 1926, the first year of their application and a year of relatively poor burn on all plots. In 1927, the burn of tobacco on limed plots was improved by sulfur, 200 pounds per acre applied in 1926, or in 1926 and 1927, and by sulfuric and orthophosphoric acids applied in 1926; it was not affected significantly or consistently by sulfur, 400 pounds per acre applied in 1926, but it was somewhat injured by sulfur, 400 pounds per acre applied in 1926 and 1927, and by the acids applied in the two years. In 1928 the burn of the tobacco on limed plots was either improved or practically unaffected by all the acidification treatments. In 1929 the fire-holding capacity of the leaf on limed plots was not reduced by the acids or by sulfur one year, but sulfur, 400 pounds per acre for two years, was associated with a poorer burn.

Considering now the burn of the tobacco on plots not limed, it appears that in 1927 the fire-holding capacity was reduced somewhat, although not consistently, by all the acidification treatments except the smallest application of sulfur; in 1928 it was either improved or practically unaffected by the acidification treatments; and in 1929 it was somewhat reduced by all acidification treatments.

However, applications of sulfur such as these would be made only to limed soil and when black root-rot made such treatments advisable; and when there were any differences, sulfur reduced fire-holding capacity more on plots not limed than on plots limed.

The amount of sulfur which may be used on tobacco land infested with Thielavia depends on the initial pH value of the soil on the one hand, and on the effect of too much sulfur on burn on the other hand. On heavily limed soil under the conditions here described, loss caused by black root-rot was reduced without injury to burn by one application of sulfur of 200 or 400 pounds per acre; but when these applications were repeated the following year, on the same plots, fire-holding capacity was impaired.

SUMMARY

Effects of acids and of sulfur in lowering the pH values of soil and on growth and black root-rot of tobacco are described.

When the pH value of soil was lowered by the application of sulfuric or nitric acids, infection by Thielavia was reduced accordingly.

When the pH value of soil was lowered, as from 5.9 to 5.0, by the application of orthophosphoric acid (alone), black root-rot of tobacco was still severe or even more severe. It is possible that salts of aluminum, instead of or in addition to hydrogen-ion concentration, inhibit *Thielavia basicola* in acid soils, and that orthophosphoric acid as well as lime inactivates such toxic substances, with consequent benefit to the fungus. An application of aluminum sulfate to the soil was found to reduce injury to tobacco caused by this fungus.

Soil pH values in field plots to which lime was last applied in 1923 were still high enough in 1930, above 5.9, to be favorable to *Thielavia basicola.*

TABLE 8.—EFFECTS OF SULFUR AND OF SULFURIC AND ORTHOSPHORIC ACIDS ON FIRE-HOLDING CAPACITY OF TOBACCO.

Plot No.	Lime treatment	Acidification treatment (Pounds per acre)	1926 crop		1927 crop		1928 crop		1929 crop	
			Seconds	Darks	Seconds	Darks	Seconds	Darks	Seconds	Darks
			Seconds	*Seconds*	*Seconds*	*Seconds*	*Seconds*	*Seconds*	*Seconds*	*Seconds*
9b, 21b	Lime	Sulfur 200, in 1926	8.1	4.2	18.7	19.4	49.5	70.5	29	21
9a, 21a	Lime	Sulfur 200, in 1926 and 1927	.....	.....	17.7	20.5	45.5	41.0	18	15
10b, 22b	Lime	Sulfur 400, in 1926	7.5	5.6	10.6	14.5	42.0	48.0	25	12
10a, 22a	Lime	Sulfur 400, in 1926 and 1927	.....	.....	9.3	8.9	35.5	45.5	16	9
11b, 23b	Lime	Sulfuric acid 1800 + orthophosphoric acid 440, in 1926	4.2	5.3	14.9	13.9	33.5	38.5	23	12
11a, 23a	Lime	Sulfuric acid 1800 + orthophosphoric acid 440, in 1926 and 1927	.....	.....	8.3	8.0	24.5	26.5	25**	18**
12, 24	Lime	None	11.1	9.5	12.9	9.4	30.5	25.5	29	15
3b, 15b	None	Sulfur 200, in 1926	.....	.....	11.0	15.4	32.5	48.5	11	11
3a, 15a	None	Sulfur 200, in 1926 and 1927	.....	.....	5.7	13.4	29.5	36.5	23	11
4b, 16b	None	Sulfur 400, in 1926	.....	.....	10.8	5.6	24.0	23.5	15	9
4a, 16a	None	Sulfur 400, in 1926 and 1927	.....	.....	9.6	5.6	31.5	30.5	11	17
5, 6, 17, 18†	None	None	8.9	5.9	11.8	9.6	26.0	35.2	26	18

* Means for duplicate plots.

** Only Plot 23a.

† Plots 5 and 17 in 1926.

Loss in yield of tobacco, caused directly by black root-rot and indirectly by lime, reached its maximum (about 44 per cent) in 1925 and 1926, the second and third years after lime was last applied. In subsequent years, this loss in yield on limed plots (in all cases as compared with yields on plots not limed) decreased so that it was about 24 per cent in 1929 and 1930.

Lowered yields on limed plots were usually associated with poorer quality.

In four out of six years, lime did not increase the fire-holding capacity of the leaf, as determined in strip tests. Abundant rainfall was associated with improved burn and had more effect than did lime on the length of time leaves held fire.

Tobacco and alfalfa were equally efficient, and much more efficient than timothy, in removing calcium and magnesium oxides from limed soil; but with no sulfur or acids applied, none of these crops caused a lowering of the pH value of the soil between 1926 and 1930.

Thielavia basicola did not infect alfalfa grown in limed soil infested with this fungus. As far as black root-rot is concerned, there is probably no reason why alfalfa cannot be grown in a rotation preceding tobacco.

The substitution of a hay crop for tobacco on over-limed, Thielavia-infested soil is not to be recommended as a means of overcoming black root-rot of later crops of tobacco.

Following timothy, brown root-rot of tobacco was equally severe on plots limed and on plots not limed.

Alfalfa or alsike clover as a cause of brown root-rot of tobacco was much less injurious than was timothy. In the second year of tobacco following alfalfa on limed soil infested with *Thielavia basicola*, there were marked increases in yields of tobacco as compared with yields of tobacco on plots on which tobacco was grown every year; but in 1930 tobacco following alfalfa (last grown in 1927 or 1928) yielded no more than did continuous tobacco.

The pH value of soil was lowered as much, or more, the year sulfur or acids were applied as in the years following. Soil pH values were lowered for four years by sulfur, 400 pounds per acre, but sulfur, 200 pounds per acre, was not enough in this soil to keep the pH value low.

The severity of black root-rot was lessened by all acidification treatments in the year of their application. Sulfur, 400 pounds per acre applied two years in succession, lessened the severity of black root-rot in these and the three following years.

Yields of tobacco on limed plots infested with *Thielavia basicola* were increased by all acidification treatments the first year the materials were applied. The application of sulfur to plots not limed, and on which there was no black root-rot, either increased yields of tobacco somewhat or did not affect them. Sulfur applied to limed plots increased yields more in the year following than in the year of its application. The optimum rate of application of sulfur to this soil, as evidenced by yields of tobacco as well as effect on burn, was nearer 400 than 800 pounds per acre. Increased yields from some of the acidification treatments have continued up to the present (1930).

Increased yields associated with acidification treatments of limed plots were accompanied in general by increased percentages of leaves of the grades lights, mediums, and seconds (as contrasted with darks and fillers).

The application of sulfur, 400 pounds per acre in one year, to limed plots reduced the fire-holding capacity of the tobacco in the year in which it was applied but not in the three years following. This is considered to be the maximum application which is safe on this soil.

LITERATURE CITED

1. Ames, J. W., and Boltz, G. E.
   1915. Tobacco. Influence of fertilizers on composition and quality. Ohio Agr. Expt. Sta. Bul. 285:173-221.
2. Anderson, P. J., and others.
   1926. Check list of diseases of economic plants in the United States. U. S. Dept. Agr. Bul. 1366, 112 p.
3. ————, and Morgan, M. F.
   1926. Black root rot and soil reaction. Conn. (State) Agr. Expt. Sta. Tobacco Sta. Bul. 6:59T-66T.
4. ————, Morgan, M. F., and Nelson, N. T.
   1927. The phosphorus requirements of old tobacco soils. Conn. (State) Agr. Expt. Sta., Tobacco Sta. Bul. 7, 24. p. illus.
5. ————, Osmun, A. V., and Doran, W. L.
   1926. Soil reaction and black root-rot of tobacco. Mass. Agr. Expt. Sta. Bul. 229:117-136, illus.
6. ————, Nelson, N. T., and Swanback, T. R.
   1928. Report of Tobacco Station at Windsor, 1927. Conn. (State) Agr. Expt. Sta., Tobacco Sta. Bul. 10:15T-82T.
7. ———— and Swanback, T. R.
   1929. Report of the Tobacco Substation at Windsor, 1928. Conn. (State) Agr. Expt. Sta. Bul. 299:141-203, illus.
8. ————, Swanback, T. R., and Street, O. E.
   1930. Potash fertilizer experiments. In Report of the Tobacco Station at Windsor for 1929. Conn. (State) Agr. Expt. Sta. Bul. 311:196-273, illus.
9. Briggs, Lyman J.
   1908. The field treatment of tobacco root-rot. U. S. Dept. Agr. Bur. Plant Indus. Circ. 7, 8 p.
10. Burkholder, W. H.
    1916. Some root diseases of the bean. (Abstract) Phytopath. 6:104.
11. Carr, R. H., and Havercamp, H. G.
    1924. Modifications of plant growth and ash content as affected by acids added to soils. Jour. Amer. Soc. Agron. 16:278-283.
12. Chapman, G. H.
    1920. Tobacco investigations. Progress report. Mass. Agr. Expt. Sta. Bul. 195:1-38, illus.
13. Doran, W. L.
    1927. Relation of the adjustment of soil reaction to black root-rot of tobacco. Science 66:661-662.
14. ————
    1929. Effects of soil temperature and reaction on growth of tobacco infected and uninfected with black root-rot. Jour. Agr. Research 39:853-872, illus.
15. Fife, E. M.
    1926. The effect of sulfur on the microflora of soil. Soil Sci. 21:245-252, illus.
16. Garner, W. W.
    1907. The relation of the composition of the leaf to the burning qualities of tobacco. U. S. Dept. Agr. Bur. Plant Indus. Bul. 105, 27 p.

17. Green, W. W.
1925. Experiments with sun-cured tobacco and other crops grown in rotation with it. Va. Agr. Expt. Sta. Bul. 242, 15 p., illus.

18. Haley, D. E.
1928. The Lancaster County leaf quality maintained by scientific soils. Tobacco 86:22.

19. Johnson, James.
1916. Host plants of *Thielavia basicola*. Jour. Agr. Research 7:289-300, illus.

20. ————, and Milton, R. H.
1919. Strains of White Burley tobacco resistant to root-rot. U. S. Dept. Agr. Bul. 765, 11 p. illus.

21. Leach, Julian G., and Rose, R. C.
1924. Experiments with inoculated sulphur for scab control. (Abstract) Phytopath. 14:57.

22. Major, T. G.
1924. Report on tobacco disease investigations. Tobacco Division, Dominion Experimental Farms, Dept. of Agr. of Canada (1923):38-41.

23. McKibben, R. R.
1928. The effect of sulphur on soils and on crop yields. Md. Agr. Expt. Sta. Bul. 296:65-114, illus.

24. Morgan, M. F., Anderson, P. J., and Dorsey, Henry.
1929. Soil reaction and liming as factors in tobacco production in Connecticut. Conn. (State) Agr. Expt. Sta. Bul. 306: 773-806, illus.

25. Murwin, H. F.
1929. The effects of magnesia, sulphur, and chlorine on the growth and quality of tobacco. In Report of the Tobacco Station at Windsor for 1928. Conn. (State) Agr. Expt. Sta. Bul. 299: 198-203.

26. Neller, J. R.
1925. Sulfofication and its effect upon the oxidation of organic matter in eastern Washington soils. Jour. Amer. Soc. Agron. 17:40-48.

27. Routt, G. C.
1920. Experiments with lime, acid phosphate, and soil fungicides on land infested with root-rot disease of tobacco. (Abstract) Science n. s. 52:40.

28. Runk, C. R.
1925. Hydrogen-ion concentration, buffer action, and soil type as a guide to the use of lime. Jour. Amer. Soc. Agron. 17:345-353.

29. Sanford, G. B.
1927. Report of the Dominion Field Laboratory of Plant Pathology in cooperation with the University of Saskatchewan, Saskatoon. Report of Dominion Botanist (1926):119-126.

30. Simon, H. R., and Schollenberger, C. J.
1925. The rate of oxidation of different forms of sulfur. Soil Sci. 20:443-449.

31. Stewart, F. C., French, G. T., and Wilson, J. K.
1908. Troubles of alfalfa in New York. N. Y. (Geneva) Agr. Expt. Sta. Bul. 305:331-416, illus.

APPENDIX

TABLE 9.- SOIL TREATMENTS AND CROPS OF EACH PLOT IN EACH YEAR.

Liming treatment	1926			1927			1928		1929 and 1930	
	No. Plot	Acidification treatment	Crop	Plot No.	Acidification treatment	Crop	Plot No.	Crop	Plot No.	Crop
		Pounds per acre			*Pounds per acre*					
None	1	None	Alsike Clover	1	None	Alsike clover	1a	Tobacco	1a	Tobacco
							1b	Alsike clover	1b	Tobacco
None	2	None	Timothy	2	None	Timothy	2a	Timothy	2a	Tobacco
							2b	Tobacco	2b	Tobacco
None	3	Sulfur 200	Tobacco	3a	Sulfur 200	Tobacco	3a	Tobacco	3a	Tobacco
				3b	None	Tobacco	3b	Tobacco	3b	Tobacco
None	4	Sulfur 400	Tobacco	4a	Sulfur 400	Tobacco	4a	Tobacco	4a	Tobacco
				4b	None	Tobacco	4b	Tobacco	4b	Tobacco
None	5	None	Tobacco	5	None	Tobacco	5	Tobacco	5	Tobacco
None	6	None	Tobacco	6	None	Tobacco	6	Tobacco	6	Tobacco
Lime	7	None	Alfalfa	7	None	Alfalfa	7a	Tobacco	7a	Tobacco
							7b	Alfalfa	7b	Tobacco
Lime	8	None	Timothy	8	None	Timothy	8a	Timothy	8a	Tobacco
							8b	Tobacco	8b	Tobacco
Lime	9	Sulfur 200	Tobacco	9a	Sulfur 200	Tobacco	9a	Tobacco	9a	Tobacco
				9b	None	Tobacco	9b	Tobacco	9b	Tobacco
Lime	10	Sulfur 400	Tobacco	10a	Sulfur 400	Tobacco	10a	Tobacco	10a	Tobacco
				10b	None	Tobacco	10b	Tobacco	10b	Tobacco

Lime	11	Sulfuric acid 1800 + ortho-phosphoric acid (80%) 440	Tobacco	11a 11b	Acids again as in 1926 None	Tobacco 11a Tobacco 11b	Tobacco Tobacco	11a 11b	Tobacco Tobacco
Lime	12	None	Tobacco	12	None	Tobacco 12	Tobacco	12	Tobacco
None	13	None	Alsike clover	13	None	Alsike clover	13a 13b	Tobacco Alsike clover	13a 13b	Tobacco Tobacco
None	14	None	Timothy	14	None	Timothy	14a 14b	Timothy Tobacco	14a 14b	Tobacco Tobacco
None	15	Sulfur 200	Tobacco	15a 15b	Sulfur 200 None	Tobacco 15a Tobacco 15b	Tobacco Tobacco	15a 15b	Tobacco Tobacco
None	16	Sulfur 400	Tobacco	16a 16b	Sulfur 400 None	Tobacco 16a Tobacco 16b	Tobacco Tobacco	16a 16b	Tobacco Tobacco
None	17	None	Tobacco	17	None	Tobacco 17	Tobacco	17	Tobacco
None	18	None	Tobacco	18	None	Tobacco 18	Tobacco	18	Tobacco
Lime	19	None	Alfalfa	19	None	Alfalfa	19a 19b	Tobacco Alfalfa	19a 19b	Tobacco Tobacco
Lime	20	None	Timothy	20	None	Timothy	20a 20b	Timothy Tobacco	20a 20b	Tobacco Tobacco
Lime	21	Sulfur 200	Tobacco	21a 21b	Sulfur 200 None	Tobacco 21a Tobacco 21b	Tobacco Tobacco	21a 21b	Tobacco Tobacco
Lime	22	Sulfur 400	Tobacco	22a 22b	Sulfur 400 None	Tobacco 22a Tobacco 22b	Tobacco Tobacco	22a 22b	Tobacco Tobacco
Lime	23	Sulfuric acid 1800 + ortho-phosphoric acid (80%) 440	Tobacco	23a 23b	Acids again as in 1926 None	Tobacco 23a Tobacco 23b	Tobacco Tobacco	23a 23b	Tobacco Tobacco
Lime	24	None	Tobacco	24	None	Tobacco 24	Tobacco	24	Tobacco

TABLE 10.—FERTILIZERS APPLIED EACH YEAR. (POUNDS PER ACRE.)

Fertilizer materials	1926	1927	1928	1929	1930
Ammo-Phos	216.2	236			
Fish	200.0	200			
Calcium nitrate	143.5	89	117.0		
Cottonseed meal	922.5	908	1107.6	1107.6	1107.6
Sulfate of potash-magnesia	233.9	247	283.0	293.9	293.9
Sulfate of potash (high grade)	131.0	131			
Urea			72.5		
Nitrate of potash			166.1	173.7	173.7
Precipitated bone			368.4	350.0	350.0
Calurea				107.2	107.2
Nitrate of Soda				92.4	92.4
Equivalent to a 5-4-5 fertilizer	**3000**	**3000**	**3500**	**3500**	**3500**

TABLE 11.—SOIL REACTION, DISEASE CONDITIONS, AND YIELD AND QUALITY OF TOBACCO IN 1926.

Plot No.	pH values of soil			Black root-rot of tobacco	Yields of tobacco per acre	Lights, mediums, and seconds	Length of time leaves held fire	
	April*	June 5	Aug. 5				Seconds	Darks
					Pounds	*Per cent*	*Seconds*	*Seconds*
1	5.5		5.5					
2	5.4		5.5					
3	5.4	5.4	5.4	Trace	1670			
4	5.3	5.3	5.4	Trace	1562			
5	5.4	5.4	5.5	Trace	1642	50	9.1	6.8
6	5.4	5.4	5.5	Trace	1688			
7	5.8		5.9					
8	5.9		5.9					
9	5.8	5.75	5.7	Moderate	1126	38	10.0	4.4
10	5.8	5.6	5.6	Moderate to mild	1241	21	7.3	6.0
11	5.8	5.5	5.7	Moderate to mild	1450	36	4.1	5.7
12	5.9	5.85	5.9	Severe	867	22	14.3	9.5
13	5.4		5.4					
14	5.5		5.6					
15	5.4	5.4	5.5	Trace	1638			
16	5.4	5.4	5.4	Trace	1560			
17	5.5	5.5	5.5	Trace	1662	46	8.8	5.1
18	5.4	5.45	5.5	Trace	1608			
19	5.8		5.8					
20	5.8		5.8					
21	5.9	5.75	5.8	Moderate	1264	39	6.3	4.0
22	5.8	5.75	5.7	Moderate to mild	1267	39	7.9	5.2
23	5.8	5.7	5.7	Moderate to mild	1500	28	4.3	4.9
24	5.9	5.9	5.9	Severe	1003	30	8.0	9.5

* Before acidification.

TABLE 12.—SOIL REACTION, DISEASE CONDITIONS, AND YIELD AND QUALITY OF TOBACCO IN 1927.

Plot No.	pH values of soil			Black root-rot of tobacco	Yields of tobacco per acre	Lights, Mediums, and seconds	Length of time leaves held fire	
	April 4	June 22	Sept. 2				Seconds	Darks
					Pounds	*Per cent*	*Seconds*	*Seconds*
1	5.7	.....	5.7	.....	.....	.....	.....	.....
2	5.7	.....	5.8	.....	.....	.....	.....	.....
3a	5.7	5.5	5.5	None	1876	29	6.5	8.0
3b	5.7	5.6	5.6	None	1785	28	9.0	19.1
4a	5.7	5.5	5.5	None	1542	17	10.8	5.2
4b	5.7	5.5	5.6	None	1951	32	12.0	6.0
5	5.6	5.6	5.7	None	1712	24	12.2	17.5
6	5.7	5.5	5.6	None	1452	19	9.8	5.9
7	5.9	.....	5.9	.....	.....	.....	.....	.....
8	5.9	.....	6.0	.....	.....	.....	.....	.....
9a	5.8	5.8	5.8	Very mild	1408	15	13.5	26.0
9b	5.8	5.8	5.8	Moderate	1245	30	24.2	25.7
10a	5.7	5.6	5.7	Trace to mild	1316	12	10.1	8.4
10b	5.7	5.7	5.8	Mild	1395	10	13.3	12.4
11a	5.7	5.7	5.6	None	1735	19	10.2	10.8
11b	5.7	5.7	5.8	Mild	1200	16	20.8	11.5
12	5.8	5.9	5.9	Moderate	892	6	6.2	10.6
13	5.7	.....	5.6	.....	.....	.....	.....	.....
14	5.7	.....	5.8	.....	.....	.....	.....	.....
15a	5.6	5.5	5.5	None	1906	31	5.0	7.7
15b	5.6	5.6	5.6	None	1821	24	13.0	11.4
16a	5.6	5.5	5.5	None	1903	33	8.4	6.0
16b	5.6	5.5	5.6	None	1887	33	9.6	5.3
17	5.7	5.6	5.7	None	1854	28	13.6	8.5
18	5.6	5.5	5.7	None	1620	35	11.7	6.5
19	5.9	.....	5.9	.....	.....	.....	.....	.....
20	5.9	.....	5.9	.....	.....	.....	.....	.....
21a	5.9	5.7	5.8	Mild to moderate	1512	18	22.0	15.1
21b	5.9	5.8	5.9	Moderate	1395	23	13.2	13.1
22a	5.8	5.7	5.8	Very mild	1506	23	8.6	9.4
22b	5.8	5.7	5.8	Mild	1573	28	8.0	16.7
23a	5.8	5.6	5.7	None*	1932	25	6.4	5.3
23b	5.8	5.7	5.8	Mild	1427	30	9.1	16.3
24	5.9	5.9	5.9	Moderate	1082	18	19.6	8.2

* Trace on one.

TABLE 13.—SOIL REACTION, DISEASE CONDITIONS, AND YIELD AND QUALITY OF TOBACCO IN 1928.

Plot No.	pH values of soil		Black root-rot of tobacco	Brown root-rot of tobacco	Yields of tobacco per acre	Lights, mediums, and seconds	Length of time leaves held fire	
	July 27	Sept. 10					Seconds	Darks
					Pounds	*Per cent*	*Seconds*	*Seconds*
1a	5.1	5.0	Trace	Severe	401	11	32	30
1b	5.3	4.7	.....	.....	.....	.....	.....	.....
2a	5.7	5.5	.....	.....	.....	.....	.....	.
2b	5.6	5.6	None	Severe	273	0	.....	16
3a	4.8	5.0	None	Trace	727	2	38	21
3b	5.2	5.2	None	None	666	13	33	50
4a	4.7	4.6	None	None	844	6	23	35
4b	5.5	5.1	None	None	844	10	24	31
5	5.2	5.4	Trace	None	784	15	25	42
6	5.2	5.1	None	Trace to mild	662	12	34	23
7a	6.5	6.3	Mild to moderate	Very severe	270	0	.	
7b	6.3	6.6	.....	.....	.....	.....	.....	
8a	6.5	6.8	.....	.....	.....	.....	.....	.....
8b	6.6	6.8	Moderate	Severe	167	0	.....	.....
9a	6.3	6.2	Moderate to severe	Trace to mild	480	3	59	32
9b	6.2	6.1	Moderate to severe	Mild	562	2	62	78
10a	5.9	5.8	Mild	None	710	20	33	51
10b	6.1	6.1	Moderate to severe	Trace to mild	711	14	38	51
11a	5.5	5.9	Mild to moderate	Trace to mild	750	15	29	33
11b	6.1	6.1	Mild to moderate	Trace	1058	37	41	41
12	6.1	6.0	Severe	Mild	874	17	36	16
13a	5.5	5.3	None	Severe	450	4	17	23
13b	5.5	5.3	. .	. . .	. .	. .	. .	
14a	5.7	5.3	.....	.....	.....	.....	.....	.....
14b	5.6	5.8	None	Severe	279	0	.....	.....
15a	5.2	5.2	None	Trace	705	12	21	52
15b	5.2	5.2	None	None	632	4	32	47
16a	4.7	5.0	None	Trace	720	10	40	26
16b	5.0	5.3	None	Trace	690	6	24	16
17	5.2	5.2	None	Trace	865	35	25	41
18	5.3	5.2	None	None	917	27	22	35
19a	6.1	6.3	Mild	Moderate to severe	940	28	38	46
19b	6.3	6.5	.	.....	..	. .		
20a	6.3	6.6	.....	.....	.....	.....	.....	.....
20b	6.3	6.1	Moderate to severe	Severe	484	4	36	22
21a	6.1	6.0	Mild to moderate	Trace	994	36	32	50
21b	5.8	6.0	Moderate	None	918	19	37	63
22a	5.3	5.9	Moderate	Trace	1055	18	38	40
22b	5.7	6.0	Moderate to severe	None	1044	17	46	45
23a	5.6	6.0	Mild	None	1185	15	20	20
23b	6.0	6.0	Mild to moderate	None	1155	27	26	36
24	6.1	6.0	Severe	None	966	25	25	35

TABLE 14.—SOIL REACTION, DISEASE CONDITIONS, AND YIELD AND QUALITY OF TOBACCO IN 1929.

Plot No.	pH values of soil		Black root-rot of tobacco	Brown root-rot of tobacco	Yields of tobacco per-acre	Lights, mediums, and seconds	Length of time leaves held fire	
	May 20	Sept. 3					Seconds	Darks
					Pounds	*Per cent*	*Seconds*	*Seconds*
1a	5.4	5.3	None	Trace	960	34	14	12
1b	5.3	5.2	None	Mild	1329	34	6	7
2a	5.3	5.3	None	Moderate	1125	29	24	6
2b	5.4	5.3	None	Mild	1372	36	13	7
3a	5.0	4.7	None	None	1500	33	15	11
3b	5.2	5.2	None	None	1473	37	14	12
4a	5.0	4.7	None	None	1366	24	12	17
4b	5.4	5.0	None	None	1545	37	6	8
5	5.2	5.3	None	None	1436	35	17	8
6	5.2	5.4	None	None	1556	45	46	23
7a	6.3	5.8	Mild to moderate	Moderate	1504	32	20	20
7b	6.3	5.8	Mild	Severe	967	20	12	5
8a	6.3	5.7	Trace to mild	Severe	780	21	25	9
8b	6.3	6.3	Trace to mild	Moderate to severe	1217	34	8	8
9a	6.1	5.9	Trace	.....	1390	34	20	13
9b	6.2	5.9	Mild	.....	1291	35	32	30
10a	5.6	5.7	Trace to mild	.....	1320	36	28	11
10b	5.9	5.7	Trace to mild	.....	1330	36	38	11
11a	5.7	5.6	Trace	.....	1393	33	.....	.....
11b	6.0	5.8	Trace	.....	1249	31	20	15
12	6.2	6.0	Mild to moderate	.....	1159	34	27	15
13a	5.5	5.3	None	Mild	1466	32	7	8
13b	5.3	5.1	None	Trace to mild	1286	18	4	5
14a	5.2	5.3	None	Trace	1245	13	6	5
14b	5.7	5.3	None	Trace	1462	36	28	24
15a	5.3	5.1	None	None	1662	32	32	12
15b	5.1	5.2	None	None	1572	36	9	11
16a	5.0	5.0	None	None	1572	28	10	17
16b	5.0	5.0	None	None	1508	30	24	10
17	5.3	5.2	None	.....	1506	36	23	18
18	5.3	5.2	None	.....	1482	33	17	22
19a	6.1	6.1	Mild	Trace to mild	1360	45	12	8
19b	6.0	6.0	Trace	Moderate to severe	1135	24	5	3
20a	6.3	6.1	Trace to mild	Moderate to severe	975	22	4	5
20b	6.4	6.2	Trace to mild	.....	1228	28	7	7
21a	5.9	6.0	Mild to moderate	.....	1426	39	13	17
21b	5.9	5.8	Mild to moderate	Trace	1385	43	27	12
22a	5.7	5.5	Trace to mild	None	1345	34	5	8
22b	5.7	6.0	Trace to mild	None	1300	35	12	13
23a	5.6	5.6	Trace	None	1411	35	25	18
23b	6.0	5.8	Trace	.....	1330	35	27	9
24	6.3	6.0	Mild to moderate	.....	1181	40	32	15

TABLE 15.—SOIL REACTION, DISEASE CONDITIONS, AND YIELD AND QUALITY OF TOBACCO IN 1930.

Plot No.	pH values of soil August 27	Black root-rot of tobacco	Brown root-rot of tobacco	Yields of tobacco per-acre	Lights, mediums, and seconds
				Pounds	*Per cent*
1a	5.2	None	None	1787	48
1b	5.0	None	None	1725	48
2a	5.2	None	None	1802	45
2b	5.3	None	Trace	1889	38
3a	5.0	None	None	1978	43
3b	4.9	None	None	1926	52
4a	4.8	None	None	1740	48
4b	4.9	None	None	1831	47
5	5.2	None	None	1848	51
6	5.0	None	None	1888	50
7a	6.1	Mild	None	1216	52
7b	5.8	Trace to mild	Moderate	1124	48
8a	6.0	Mild to moderate	Moderate	1339	43
8b	5.9	Moderate	None	1368	49
9a	5.7	Trace to mild	Trace to mild	1458	41
9b	5.8	Moderate to severe	None	1428	39
10a	5.4	Trace to mild	Trace	1592	41
10b	5.9	Trace to mild	None	1573	42
11a	5.5	Mild to moderate	None	1592	34
11b	5.5	Trace to mild	Moderate	1329	37
12	5.8	Moderate to severe	None	1476	50
13a	4.7	None	None	1757	37
13b	5.0	None	Trace to mild	1654	45
14a	5.1	None	None	1797	39
14b	4.9	None	None	1874	54
15a	4.7	None	None	2052	48
15b	5.0	None	None	1978	48
16a	4.5	None	None	2018	45
16b	4.8	None	None	1872	46
17	5.1	None	None	1921	45
18	4.9	None	None	2039	45
19a	6.1	Mild	None	1524	50
19b	6.1	None	Trace	1577	43
20a	6.3	Mild to moderate	None	1661	53
20b	6.3	Mild to moderate	None	1585	47
21a	6.3	Mild to moderate	None	1657	53
21b	6.2	Mild	None	1589	63
22a	6.0	Trace to mild	None	1677	49
22b	5.7	Trace to mild	None	1667	37
23a	5.8	Mild	None	1703	43
23b	5.9	Mild to moderate	None	1517	43
24	6.1	Mild to moderate	None	1324	49

PUBLICATION OF THIS DOCUMENT APPROVED BY THE COMMISSION ON ADMINISTRATION AND FINANCE.
3M-7-'31. No. 2887.